

Waves in Modified Gravity

Cosmic Tsunamis

Arxiv.org: 1607.02600

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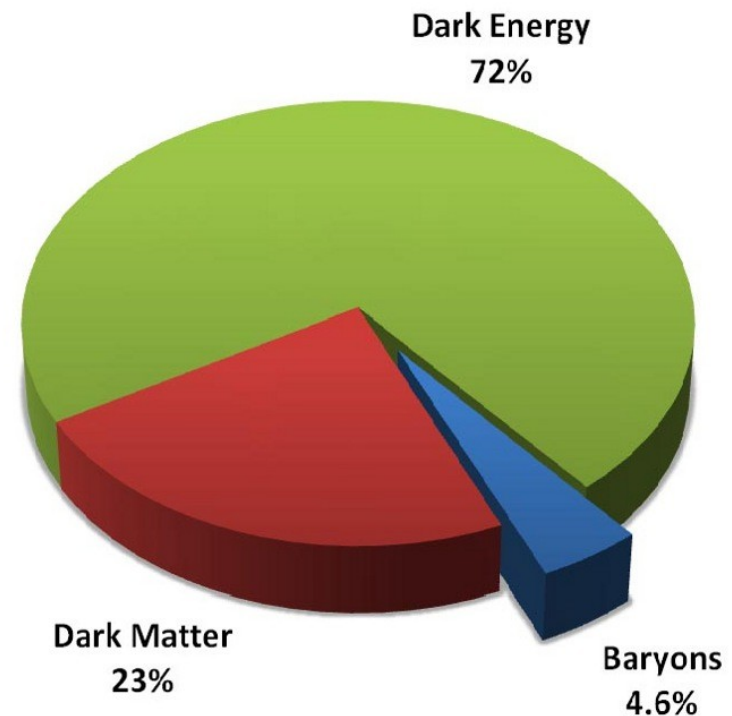


Overview

- Why Modify Gravity
- Screening
- The Quasi-Static Approximation
- The Spherical Wave Model
- Results when Applying Waves
- How are Waves Made?

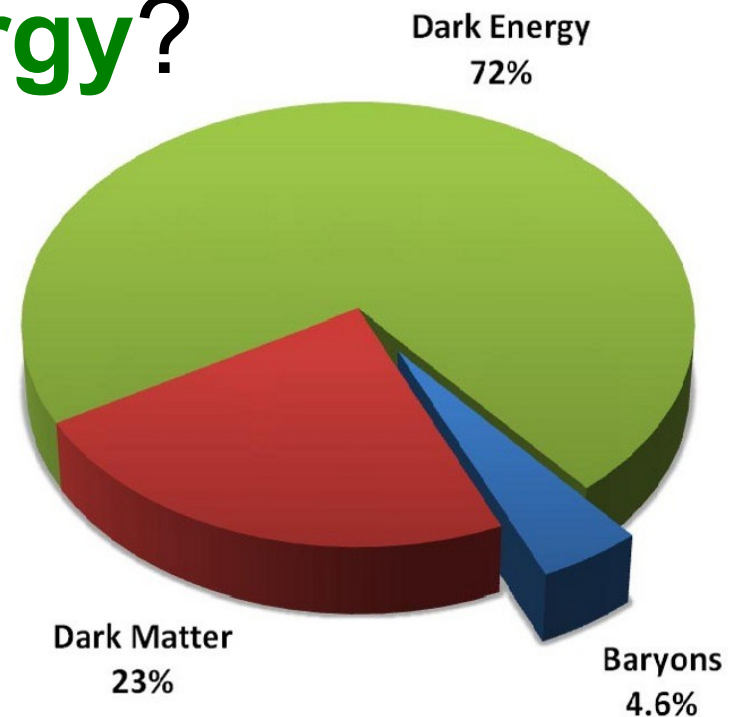
Why Modify Gravity

- Standard model - Λ CDM
Works well on large scales...



Why Modify Gravity

- Standard model - Λ CDM
Works well on large scales...
- What is **Dark Energy**?
- Is Λ natural?
- **Dark Matter**?



Modified Gravity and Screening

- Start with General Relativity
- Add some small terms (not *too* small)

Modified Gravity and Screening

- Start with General Relativity
- Add some small terms
- GR is well tested in the solar system, $\gamma \approx 1$ ($\pm 10^{-5}$)
- **Screening**: Equations reduce to GR, $\gamma \rightarrow 1$, in the solar system

Scalar-Tensor Theories

- A scalar field ϕ in the EH action

$$S = \int \left[\sqrt{-g} \left(\frac{R}{16\pi G} - \frac{1}{2} \phi'^{\mu} \phi_{,\mu} - V(\phi) \right) + \sqrt{-\bar{g}} \bar{\mathcal{L}}_m \right] d^4x$$

- A **conformal** coupling to matter

$$\bar{g}_{\mu\nu} = A(\phi) g_{\mu\nu}$$

- Example: **Symmetron**, $A = 1 + \phi^2/M^2$

Quasi-Static Scalar Fields

- Scalar field equation of motion (KG)

$$\ddot{\phi} + 3H\dot{\phi} - \frac{1}{a^2}\nabla^2\phi = -V_{\text{eff},\phi}(\rho, \phi)$$

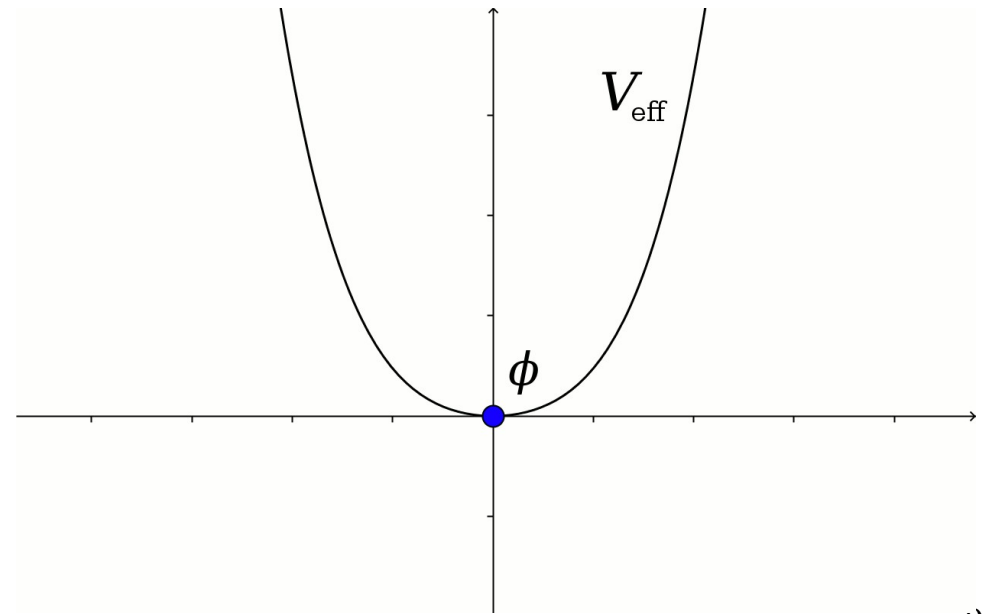
- A damped **wave equation**

Quasi-Static Scalar Fields

- Scalar field equation of motion

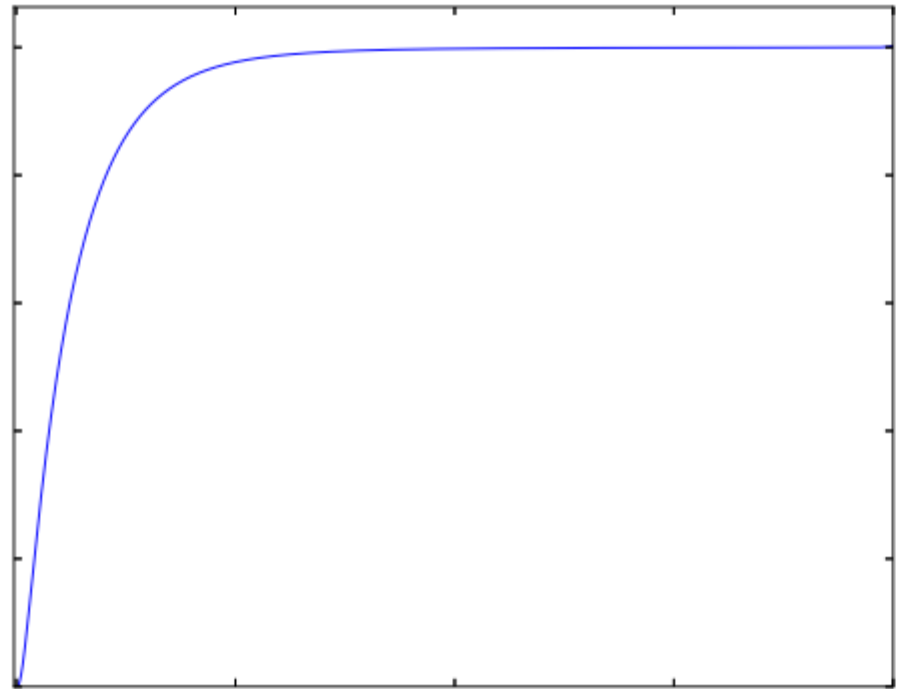
$$\ddot{\phi} + 3H\dot{\phi} - \frac{1}{a^2}\nabla^2\phi = -V_{\text{eff},\phi}(\rho, \phi)$$

- **Wave equation**
- **Quasi-static**
approximation:
Poisson eq.

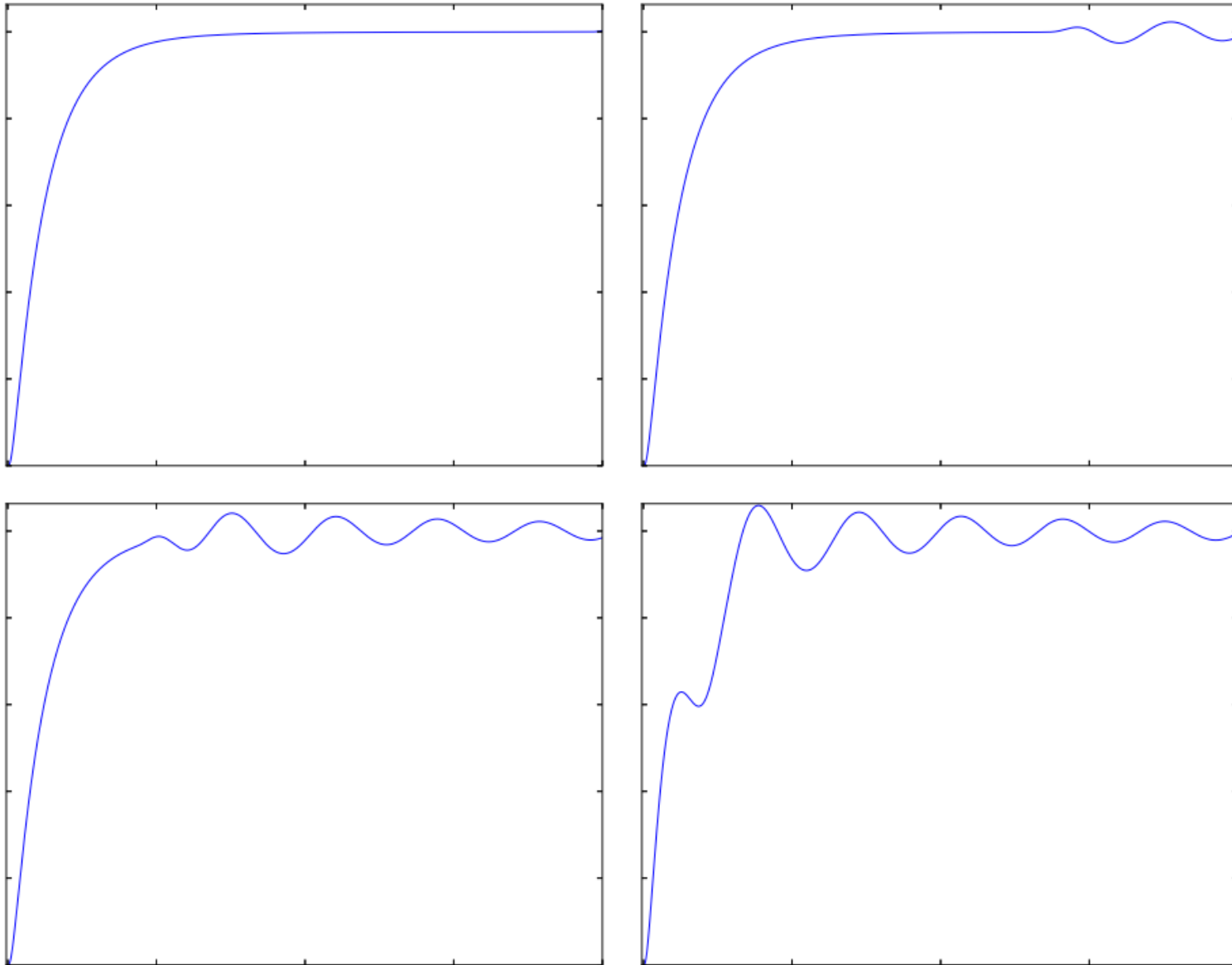


Spherical Wave Model

- Spherically symmetric, static density
 - NFW fitted to the Milky Way
- Waves travelling in radial direction



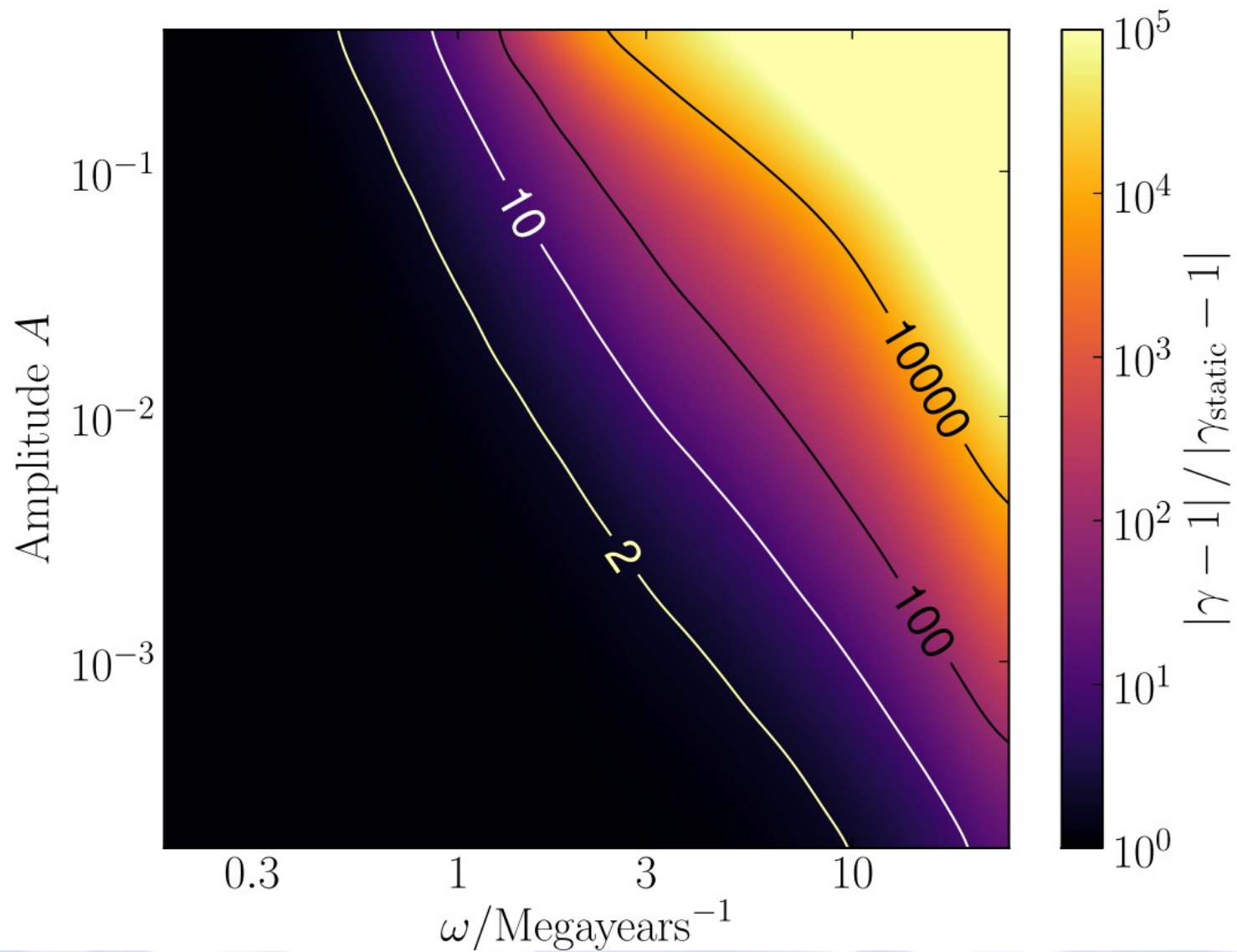
Spherical Wave Model



Results

- The field perturbed close to center
- Frequency and amplitude dependent

Results



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- The field perturbed close to center
- Frequency and amplitude dependent
- $\gamma - 1$ increased many orders of magnitude

How to Create Waves?

- In the Symmetron:
 - Spontaneous Symmetry Breaking (SSB)
 - Collapsing topological defects (domain walls)

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- In the Symmetron:
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- Other Scalar-Tensor theories:
 - Neutron star collisions
 - Massive binaries
 - Super-massive black holes

Conclusions

- Scalar-Tensor theories need **screening**
- Many models assume **quasi-static** field
- Waves can disrupt quasi-static screening

Conclusions

- Scalar-Tensor theories need **screening**
- Many models assume **quasi-static** field
- Waves can disrupt quasi-static screening
- **Any theory**: check if waves are important!
 - Valid screening?
 - Stricter parameter constraints?
- Can lead to new models and probes